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Production costs of the non-ferrous metals in the EU and other countries: Copper and zinc

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A B S T R A C T

Our study compares production costs of the non-ferrous metals (NFM) industry in the European Union (EU) and other countries in order to understand whether these costs are higher in Europe. Our analysis focuses on copper and zinc, since they are considered to be the most greatly consumed non-ferrous metals after aluminium. The countries selected for comparison depend on the metal and are based on high shares of extra-EU28 trade and/or of global installed capacity. A bottom-up approach has been followed, based on information at facility level for primary production of the two metals. The analysis includes 32 copper smelters, 34 copper refineries and 23 zinc smelters, representing 72%, 58% and 30% of global production of copper anodes, cathodes and zinc slab respectively. Taking into consideration the complex structure of the industry, costs are broken down to three components: (1) Energy, (2) Labour and other costs (salaries, consumables and other on-site costs) and (3) Credits (due to co-products). Our findings suggest that although interesting observations emerge in each of these components, overall costs compare more favourably among countries than initially thought. The EU industry does not have the highest production costs. On the contrary, especially in the case of copper refineries and zinc, it has lower production costs than most of the countries included in the study.

1. Introduction

Discussions concerning the competitiveness of the European industry, both in the industry and in the European Commission, have raised the issue of cost differences between Europe and other countries. In the communication "For an European Industrial Renaissance" (European Commission, 2014a) it was acknowledged that production costs, especially energy costs, might be higher in Europe than in other competitor states.

The non-ferrous metals industry includes a number of metals distinguished from the ferrous ones thanks to their non-magnetic properties and their resistance to corrosion. Aluminium is the mostly used one, while the second and third highest usages are for copper and zinc (European Commission, 2014b). Studies usually focus on energy use and CO_2 emissions of the nonferrous metals industry (Yanjia and Chandler, 2010; Lucio et al., 2013) or generally energy-intensive industries (Makridou et al., 2016) or on the impact of environmental legislation on competitiveness (Demailly and Quirion, 2008; Meleo, 2014; Korhonen et al., 2015; Söderholm et al., 2015). Studies on economic assessment of energy-intensive industries are limited (Scholtens and Yurtsever, 2012; Ren et al., 2009). There are some studies that assess production costs of non-ferrous metals (NFM) (Figuerola-Ferretti, 2005; Adams and Duroc-Danner, 1987), all referring to aluminium, or the economics of energy policies on copper production (David and Zandi, 1979), but they are all not recent. Only one report was identified that aimed at providing the European Commission with an up-to-date understanding of the competitiveness of the EU NFM industry, that included not only aluminium, but also copper, zinc and other metals (ECORYS, 2011).

It has been observed that copper and zinc have received limited attention in literature, although together with aluminium they represent more than 85% of annual global NFM production (ECORYS, 2011). As a result, the goal of the present study was to establish the different parameters that affect production costs of both metals.

For both copper and zinc there are two processes that can be applied to produce primary metal: hydrometallurgical and pyrometallurgical. In the case of copper it is rather the latter used (80% of primary copper worldwide (Richardson, 2000)), while in the case of zinc the former accounts for about 90% to 95% of total world output (European Commission, 2014b; Schwab et al., 2015).

Excluding mining, the copper industry consists of smelters and refineries. Smelters process sulphuric concentrates of low-grade copper ores, originating from mines, and produce copper anodes,

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while refineries produce copper cathodes from copper anodes. Copper cathodes have purity between 99.97% and 99.99% and in a further step can be melted and cast in different shapes of semi-finalised products, such as billets, cakes or wide rods. The two processes can be either in the same site or in different ones.

In the zinc industry, on the other hand, both smelting and refining usually take place on the same site. Starting material is usually sulphuric zinc concentrates that in an intermediary step need to be oxidised, and the final product is zinc deposited on the cathodes, from where it is collected, melted and cast into slabs or ingots.

In 2013 global copper mine production was estimated to be about 18.3 Mt, with Chile being the largest producer, followed by China, Peru and the USA (U.S. Geological Survey (USGS), 2015), while global smelter production of copper reached 13.8 Mt if only primary production is considered (Minerals U.K., 2015) or 16.8 Mt if also secondary production is included (International Copper Study Group (ICSG), 2014). China accounted for about 27% of this production and the EU and Chile for 11% and 10%, respectively. Global refinery production of copper was 20.9 Mt, including 3.8 Mt of secondary refined production (Minerals U.K., 2015; International Copper Study Group (ICSG), 2014), 31% of which was located in China and 13% in the EU. The European Union is relying highly on imports of ores and concentrates. In 2013, the industry imported copper ore mainly from Chile, Peru and Brazil (Eurostat, 2016a), whereas Chile (44%), Peru and Zambia were the origin of imports of refined copper in the form of cathodes (Eurostat, 2016b).

Concerning zinc, global slab production in 2013 reached 13.2 Mt (Minerals U.K., 2015), with China being the largest producer both in mining and smelting. China's share of slab production was 40% and the EU's 15%. In the same year, total extra-EU imports of refined zinc were 0.16 Mt and exports 0.38 Mt (Eurostat, 2016b). Most of refined zinc was imported from Norway and Namibia, while historically Russia and Kazakhstan have also had high percentages of trade with the EU.

2. Methodology

2.1. Boundaries and method

As already mentioned, in this analysis we assessed if production costs of copper and zinc in Europe are higher than in other competing countries. For this comparison the chosen countries were based on EU imports data (Eurostat, 2016a, 2016b). For copper the countries selected were China, Chile, Peru and Zambia, while for zinc the comparison was done among the EU, China, Russia, Kazakhstan, Norway and Namibia. China was also included because of its leading position as global producer, even if it had a low trading share with the EU.

In order to evaluate the costs of manufacturing processes, we follow a bottom-up approach based on information at facility level provided by Wood Mackenzie (Wood Mackenzie, 2015a). The database covers more than 90% of total primary production from copper smelters worldwide and about 93% of the Chinese copper production in 2013 (Wood Mackenzie, 2015b). In the case of zinc, the global coverage is over 80%, including all of China with the exception of very small smelters, resulting in about 65% total production coverage in this country (Wood Mackenzie, 2015c). The analysis was done for 2012 and 2013.

The facilities covered fall with classes 24.43 and 24.44 of the NACE REV.2 classification. The boundaries of our study were at the gate of smelters or refineries. This means that we included neither mining and preparation of ores, nor casting carried out after manufacturing of copper cathodes and zinc slab or ingot. We also did not include any copper produced at the mine-site following the hydrometallurgical route, which as mentioned before represents about 20% of global primary copper (Richardson, 2000). The analysis was based mainly on primary production of the metals. Even if the European recycling industry is among the most advanced in the world and the savings compared to primary route could reach up to 85% in the case of copper (Grimes et al., 2008), both energy consumption and costs in secondary production are strongly depending on the quality of the scrap. In addition, there is no commercial or public information available about global recycling of zinc and copper with the required degree of detail. Because of these two reasons, we excluded secondary production costs from the comparison. It should be noted that other studies (ECORYS, 2011) also reported difficulties in distinguishing between energy costs for primary and secondary processing.

Table 1 shows the number of facilities included in the database and therefore in this study. The differences between 2012 and 2013 were that a new copper smelter started operating in China adding 0.5 Mt in the total capacity of the country, one copper refinery closed down but another started also in China incrementing Chinese total refinery capacity 0.4 Mt and a zinc smelter in Bulgaria closed down.

2.2. Components of the cost

Our analysis did not include depreciation and was focused entirely on production costs of the primary route. Costs in this study were broken down to three components:

a. Energy
b. Labour & other costs
c. Credits (due to the value of co-products)

Energy costs include electricity and other fuels such as natural gas, fuel oil, coal or coke used in the facilities. Copper smelters are high consumers of energy, although to a much lesser extent than the aluminium ones. Copper refineries are also power intensive processes. The major source of energy in electrolytic zinc smelters is electricity.

Labour and other costs consist of salaries for supervision, operation and maintenance, as well as maintenance items, consumable and other on-site costs. Maintenance items generally refer to everything used to keep the smelter operational, while consumables to everything used to operate the smelter. The range of items covered is wide and depends on the technology used. Other on-site costs include services such as water and communications, rates and property taxes and infrastructure costs such as general site maintenance. These costs usually depend on local factors and are not necessarily proportional to capacity.

Valuable co-products were taken into consideration as credits, which were deducted from total expenses. For copper, credits originate from sulphur by-products in the case of smelters and from nickel salts and cathode premiums in the case of refineries.

The most common copper ores are sulphuric, with sulphur contents varying significantly. High sulphur content may have impact on the energy balance of the smelter, affecting its operation. Nevertheless, the driving force behind producing sulphuric by-products (mainly sulphuric acid, but in some cases also gypsum and liquid SO_2) in the industry is environmental regulations rather than economic factors. Environmental legislation in Latin America has become more stringent in recent years. Europe has in general high total sulphur collection efficiencies, reflecting the stringency of environmental legislation. Global trends in the base years of the study (2012 and 2013) were that sulphur prices were decreasing. The acid selling price for individual smelters was almost entirely based on the region in which the smelter is located.

Table 1
Number and capacity of copper smelters and refineries and zinc smelters in 2012, in the countries considered for each metal.

Countries	Copper smelters		Copper refineries		Zinc smelters	
	Number	Capacity (Mt)	Number	Capacity (Mt)	Number	Capacity (Mt)
Chile	7	2.0	3	1.1		
Peru	1	0.4	1	0.3		
Zambia	3	0.6	2	0.5		
EU	8	2.5	12	2.7	11	2.0
China	13	4.4	16	5.1	6	1.0
Russia					2	0.3
Kazakhstan					2	0.3
Norway					1	0.2
Namibia					1	0.2
Total	32	9.9	34	9.7	23	4.0

In most refineries, nickel originates in the anodes and is an impurity that needs to be removed so as to ensure the quality of copper cathode. It is recovered from the electrolyte as a by-product, usually as nickel sulphate. Nickel removal does not always offer the opportunity of a financial return, as it is an impure product that cannot be avoided. Cathode premiums, on the other hand, are part of the revenue of refineries and used to reflect the quality of final product, but in more recent years have been connected to the projected supply and demand situation and freight costs to customers. They are included in the analysis, since disregarding them would distort net costs of the copper industry.

Besides these co-products, it is worth mentioning that the copper and zinc industry also produces other metals such as gold, silver, selenium and tellurium in the case of copper, or lead, silver, cadmium and germanium for zinc. A portion of these metals is paid back to the mines, but the remaining could generate credits. Unfortunately, there is no consistent data concerning these by-products and how they are managed between the smelters/refineries and the mines. As a result, these valuable co-products could not be included in the current study.

It should be noted that raw materials costs were not considered as a component of the production cost. This is due to the nature of the non-ferrous industry. Mines produce copper concentrates that are sold to smelters and refineries for their copper content. The income of mines is a function of mainly the final metal price and the quality of concentrate. The final price of base metals is decided in international metal exchanges, most importantly the London Metal Exchange (LME), but also the Shanghai Futures Exchange (SHFE) and the Commodity Exchange Inc (COMEX) (ECORYS, 2011; Nussir, 2015). The final price paid for the finished product consists of the price determined on the metals exchange plus a regional cathode premium (ECORYS, 2011). Smelters and refineries require concentrate specifications that limit the amount of impurities allowable in concentrates, otherwise financial penalties are levied. Typically, after treatment charges (TCs) and refining charges (RCs), the smelter pays to the producer 96–97% of the metal value contained in the concentrate (Nussir, 2015). TCs and RCs are usually fixed on annual basis. RCs exist only in the case of copper, while TCs in both copper and zinc.

To conclude, raw material prices are set in the global market and usually passed on directly to customers, thus they are not considered a source of competitive advantage or disadvantage. Therefore, we excluded raw material prices from this competitiveness analysis that is solely linked to factors such as energy prices, labour costs and to a lesser extent to exchange rates.

2.3. Prices and consumptions

The general formula used for estimating the components of the costs was:

$$\text{Cost} = \text{Consumption or Production} * \text{Price}$$

Co-products yields and consumptions of electricity and fuels are technology specific and expressed as MWh of electricity or tonne of fuel and co-product per tonne of main product. The values used in this study were based on literature (European Commission, 2014b; Richardson, 2000; Grimes et al., 2008; Nussir, 2015) and the Wood Mackenzie database (Wood Mackenzie, 2015a).

Exceptions to this general formula were labour, nickel sulphate credits and cathode premiums. Labour was a function of manpower, productivity and the hours worked in the plant multiplied by the cost of man-hours. For nickel sulphate, on the other hand, the database (Wood Mackenzie, 2015a) assumed that on average sulphate contains 22% nickel and that the refinery obtains a net return equivalent to 60% of the contained metal. This methodology was applied only to refineries that report production of nickel. The price assumed for 2012 was 1815 EUR/$t_{\text{nickel sulphate}}$ and for 2013 1493 EUR/$t_{\text{nickel sulphate}}$ (Wood Mackenzie, 2015a). On the contrary to nickel sulphate prices, cathode premiums were reported directly from refineries.

Tables 2 and 3 include average values of consumptions and prices respectively, used in calculating the components of the costs for 2013 as base year.

Table 2 provides raw materials consumption, aggregated electricity and total net energy consumption (including electricity). Net energy consumption was the total energy consumed in processes minus credits for power or steam generated. In copper smelters, energy was consumed in extracting copper from concentrates to produce anodes and in associated processes, such as oxygen and acid plants. In refineries, it corresponded to the electrolytic refining process, including on-site anode casting where appropriate and waste heat steam supplied by an associated smelter for heating. However, waste heat from integrated anode casting plant was not taken into consideration. For zinc, the net energy consumption was based on the total process of extracting zinc from raw materials, including power generated inside the facility as credit. Energy consumption is not disaggregated further to individual fuels in Table 2, as the energy mix in the different facilities varied significantly.

Table 3 illustrates prices in 2013 for different energy sources, usual co-products and labour. It should be noted that Table 3 shows average values for all three types of facilities (copper smelters, copper refineries and zinc smelters), while in the analysis individual values were applied. These individual values were in some cases facility- or technology-specific and in other cases country-specific. The EU is also different compared to the other countries, as it consists of 28 Member States, but in the tables we provide only average values of all EU countries.

For each facility the three components of the cost were

Table 2
Raw materials, energy consumptions and productivity in the copper and zinc industry in 2013.

Consumptions		EU	China	Chile	Peru	Zambia	Russia	Kazakhstan	Norway	Namibia
Copper smelters	Concentrates (t/t Cu_{anode})	3.43	4.05	3.60	3.89	3.53				
	Electricity (MWh/t Cu_{anode})	1.10	1.90	1.20	1.11	1.39				
	Total net energy (GJ/t Cu_{anode})	9.57	9.92	9.44	8.57	11.22				
	Productivity (t Cu_{anode}/man)	489	261	255	403	297				
Copper refineries	Anodes (t/t $Cu_{cathode}$)	1.17	1.20	1.21	1.22	1.22				
	Electricity (MWh/t $Cu_{cathode}$)	0.40	0.35	0.35	0.30	0.52				
	Total net energy (GJ/t $Cu_{cathode}$)	2.43	3.08	2.52	1.09	2.83				
	Productivity (t $Cu_{cathode}$/man)	1877	717	585	597	435				
Zinc smelters	Concentrates (t/t Zn)	1.99	2.54				2.11	2.36	1.84	11.29
	Electricity (MWh/t Zn)	3.76	4.06				4.44	4.60	4.50	4.60
	Total net energy (GJ/t Zn)	19.98	21.94				31.35	37.85	16.31	16.59
	Productivity (t Zn/man)	341	85				81	123	535	264

Table 3
Prices of energy used, labour and credits in the copper and zinc industry in 2013.

	Electricity (EUR/ MWh)	Natural gas (EUR/ MWh)	Fuel oil (EUR/t)	Sulphuric acid (EUR/t)	Cathode premium (EUR/t $Cu_{cathode}$)	Hourly labour (EUR/h)
EU	58.9	35.6	648.0	24.1	28.0	28.4
China	60.6	23.9	610.5	9.3	35.6	2.4
Chile	105.9	62.3	512.2	57.8	−5.6	24.6
Peru	86.2		552.4	51.3	−56.2	14.4
Zambia	43.3		574.5	106.2	−28.9	3.8
Russia	56.2	9.7		32.3		7.0
Kazakhstan	18.9		539.1	23.0		7.1
Norway	39.1		842.6	29.8		55.3
Namibia	19.6					11.0

estimated, based on the individual characteristics of it, such as size, technology used and location. Then for each country the average was calculated weighted according to capacity:

$$\text{Weighted average} = \sum (Capacity \times Cost) / \sum Capacity$$

The total production costs for each country are the sum of the weighted averages of the three components for this country.

3. Results and discussion

Following the methodology explained before, we were able to produce comparative values for the various countries selected per metal. Fig. 1 summarises the overall average production costs for copper smelters and refineries and for zinc smelters.

As it can be seen from the disaggregated values in Fig. 1, total expenses (energy and labour) in 2013 were lower than in 2012, thanks mainly to lower electricity prices in 2013. But as credits were also lower in 2013, total production costs increased in the majority of the countries.

In the case of copper, energy costs in most countries were about 30–35% of total expenses of smelters and refineries, and labour and other costs the remaining 65–70%. These figures agree with the cost structure suggested by ECORYS (ECORYS, 2011). The only exception was China, where labour costs were still much lower than in the rest of the countries, as China had the lowest hourly rates among the countries compared (Table 3).

South America had much higher production costs than Europe, China or Zambia. All components of the costs in Chile and Peru were higher than in the rest of the countries compared. Chile had the highest electricity price compared to all copper producing countries (Table 3), justified by the fact that in this country there has been a shortage of electrical power as a result of increasing consumption and lack of investments in the power generation infrastructure (Wood Mackenzie, 2015b). In addition, labour costs were also high in the two countries of South America. In recent years there has been an increasing number of claims to get higher labour remuneration rates within the copper industry, mainly due the increase in copper prices. Much of the wage inflation pressure in smelters originated in the mining industry and it is notable that many of the smelters with the highest wages have been those directly tied to a local mine, such as the majority of Chilean smelters (The Economist, 2015; Sanderson, 2015). Chilean refineries had also the highest labour costs (Fig. 1(c)), although Chile did not have the most expensive hourly labour as shown in Table 3. Europe (EU and Norway) had higher hourly rates. Nevertheless, these countries also had high productivity thanks to the use of more automated plants and hence labour costs were minimised.

Concerning credits, as already mentioned, sulphur prices tend to decrease, a fact that reflected in Fig. 1(a) and (e) for copper and zinc, respectively. An important factor affecting the price of sulphur by-products in the copper industry is when a smelter sells its acid on an intra-company transfer basis, for example for a metallurgical operation. Such arrangements typically occur in the Latin and North American regions, thus the credits in Chile and Peru were higher than in the rest of the world. High sulphuric acid were also noticed in Zambia (Table 3), mainly because of high transport costs and long distances, as well as the fact that Zambia's industry is based on oxide ores and not sulphuric ores as in the rest of the countries, making sulphuric acid rare.

Particularly in the case of copper refineries, as they are consuming less electricity than smelters (Table 2), the decrease in electricity prices did not greatly influence total expenses. On the other hand, in some cases cathode premiums were not enough to cover the costs related to the supply and demand situation and therefore they seemed to be penalties to refineries which are distant from their markets and long overland transport costs magnify this effect. This phenomenon was more visible in Zambia and in Peru in 2013.

In the zinc industry (Fig. 1(e) and (f)), except for Russia, there were less remarkable differences among the countries compared. Russia had the highest production costs, while costs in Europe were comparable to the ones in China. Once again the difference in labour costs between China and the rest of the countries was obvious.

As average values do not give a clear idea of the range of variability of the costs, we also include in Fig. 2 the maximum and minimum values and average total specific costs and the same information for a breakdown of the costs in each country. Each curve represents a component of the cost, and for each curve the countries are ranked according to their increasing average costs. Each vertical line joins the minimum and maximum cost estimated for each country according to their different performances

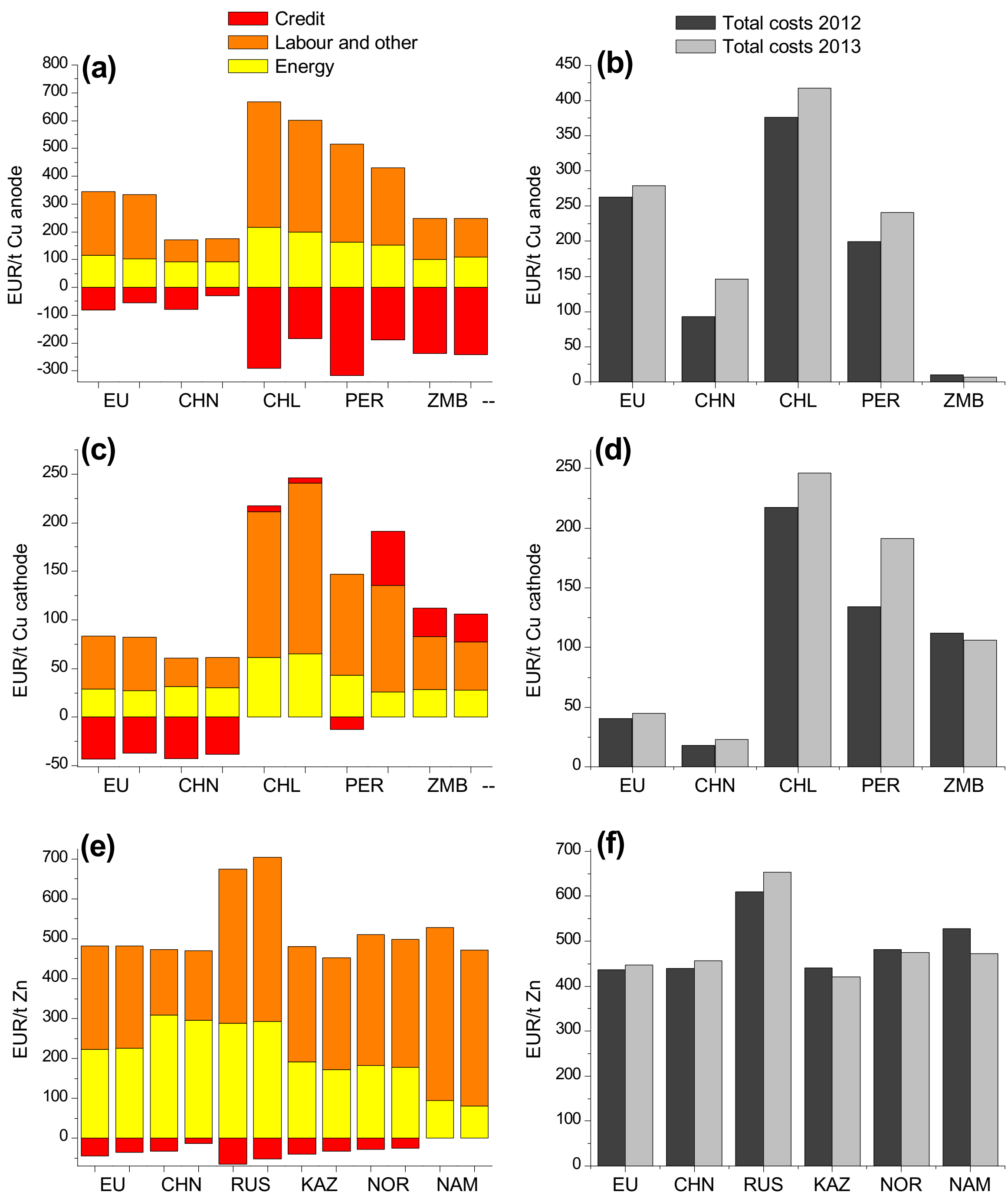

Fig. 1. Summary of total production costs for copper and zinc (a) copper smelters costs per component, (b) total costs for copper smelters, (c) copper refineries costs per component, (d) total costs for copper refineries, (e) zinc smelters costs per component and (f) total costs for zinc smelters.

and prices. If there is no vertical line in the figures, it means that either there is no variation among facilities of the corresponding country or there is only one plant. Here we discuss only the results for 2013.

From Fig. 2(a), it can be seen that the minimum of total production costs in EU copper smelters is similar to the Chinese average. Chilean smelters, on the other hand, as already seen, had much higher total production costs than EU, although Chile represented the majority of European imports of final copper products in 2012 and 2013. It is interesting to note that average energy costs in Europe were the second lowest among the countries compared, although they are usually the ones recognised as possibly higher than competitors (European Commission, 2014a). The main reason EU production costs were not lower than Peru and China was due to higher credits and lower wages respectively.

In the case of copper refineries (Fig. 2(b)), the EU industry was much more competitive than most of the countries from which copper cathodes were imported. It should be mentioned again, that the EU was not importing from China in the period 2006–2014 (Eurostat, 2016a). The analysis of variability of costs showed that there were no big variations in the production costs of European refineries and the average European production cost was towards the second lowest.

Concerning zinc smelters, we observed again homogeneous total average costs among most countries, with only exception Russia (Fig. 2(c)). It is worth noticing though, that the maximum

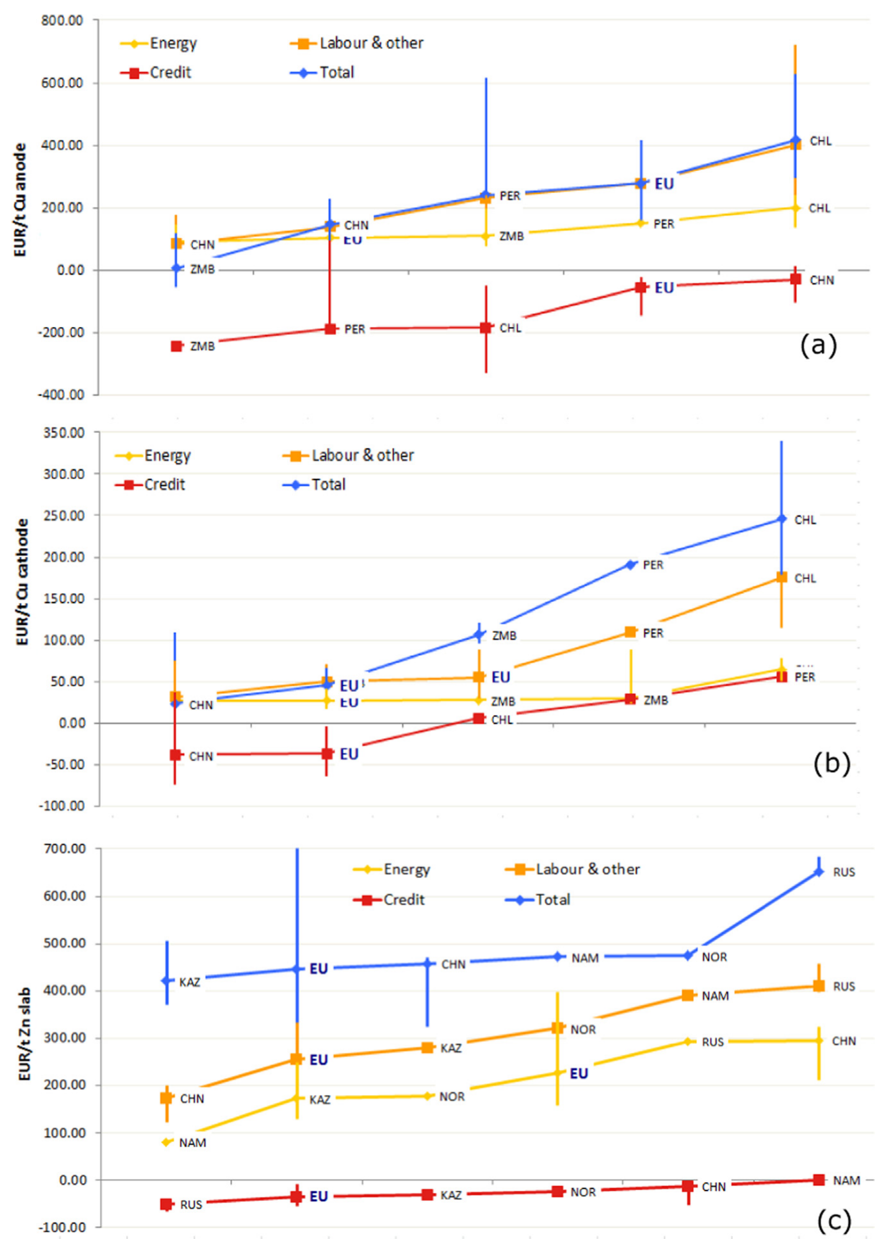

Fig. 2. Average cost-curves and intervals encompassing the maximum and minimum for 2013 (a) copper smelters, (b) copper refineries and (c) zinc smelters. Note for this figure: this figure is produced through excel with the use of macros. It is attached as picture because its components are sensitive to movements.

production costs in the EU were higher than the Russian ones. The great variation in the EU values could be attributed to the big differences in electricity prices in the member states. Nevertheless, the average energy costs in the EU could not be clearly considered much higher than in competitive countries.

4. Conclusions

The aim of the present study was to evaluate if production costs in the European copper and zinc industry are higher than in other countries, as it has been claimed for the European industry in general. The countries selected for comparison included China, as it is the leading production country in the world for both metals, and countries from which the EU has currently or historically high percentages of imports of the final products considered in this study. These countries were Chile, Peru and Zambia for copper and Russia, Kazakhstan, Norway and Namibia for zinc.

Copper industry is distinguished in two parts: smelters with final product copper anodes and refineries with final product copper cathodes. Zinc industry consists of only smelters with final product zinc slab or ingot. In 2012 total average costs in the EU were 263 EUR/t Cu_{anode}, 40 EUR/t $Cu_{cathode}$ and 437 EUR/t Zn, for copper smelters, copper refineries and zinc smelters respectively. In 2013 total average costs were 279 EUR/t Cu_{anode}, 45 EUR/t $Cu_{cathode}$ and 447 EUR/t Zn, respectively.

From our analysis we concluded that the EU zinc and copper cathodes industries were more competitive than their major competitors. The EU copper anodes industry was more competitive than Chile (417 EUR/t Cu_{anode} in 2013), comparable to Peru and China and less competitive than Zambia. In the case of copper refineries, the European copper industry had much lower production costs than the countries from where most of imports of copper cathodes were originating. Due to high automation and high cathode premiums, the European average was comparable to the average costs in China (23 EUR/t $Cu_{cathode}$ in 2013). The zinc

European industry had similar production costs as Kazakhstan, which had the lowest ones (421 EUR/t Zn in 2013), and much lower than Russia, with the highest ones (653 EUR/t Zn). In particular, energy costs in the EU copper and zinc industries were not found to be higher than the main competitors.

Because of the special structure of the non-ferrous metals industry market, copper smelting and refining companies pay back to mines the price of copper cathode set in the London Metal Exchange (LME) after deducting treatment and refining costs. Equivalently, zinc smelting companies pay back to zinc mines the price of zinc settlement set in the LME after deducting treatment costs. The average international prices of copper Grade A in the LME were 6244 EUR/t in 2012 and 5520 EUR/t in 2013, while for zinc settlement were 1439 and 1528 EUR/t for 2012 and 2013 respectively (Inees, 2015). According to facility data (Wood Mackenzie, 2015a), for 2013 the average charges in the copper industry ranged between 266 EUR/t $Cu_{cathode}$ in Europe and 435 EUR/t $Cu_{cathode}$ in Zambia and in the zinc industry between 259 EUR/t Zn in Namibia and 373 EUR/t Zn in China. From these values it is obvious that the major part of the metal price is mining charges. According to Eurostat data (Eurostat, 2016a) in the European Union the average import price paid for copper concentrates in 2013 was 5212 EUR/t $Cu_{cathode}$ and for zinc concentrates 993 EUR/t Zn, supporting the conclusion drawn from the comparison of LME prices and TCs/RCs. It should be noted though, that since depreciation has not been included in this analysis, any further conclusions should include this other component too. Nevertheless, the fact that Europe has the lowest copper treatment and refining charges and one of the lowest zinc treatment charges (291 EUR/t Zn in the EU and 289 EUR/t Zn in Norway) could be translated as a sign of the competitiveness of these industries, even if Europe does not have metal natural resources big enough to cover European consumption.

It should be mentioned that this study did not include any copper cathodes produced at the mine-site by the hydrometallurgical route. This route may have lower cost than the smelting-refining route, but it represents only 20% of global primary copper production (Figuerola-Ferretti, 2005). In addition, it is important the fact that the European industry has a higher rate of recycling than the rest of the world. In the case of copper it was estimated that in 2012 the percentage in global scale was about 20% (Söderholm et al., 2015), while in the EU about 40% is covered by secondary raw materials (European Commission, 2014b). Recycling was excluded of our analysis due to lack of data and because of the high dependence and variability of costs and energy consumptions in secondary route on the quality of scrap. Also because of similar reasons, credits from other metals co-produced could not be taken into consideration, although they would decrease the production costs. They are expected to be higher in the European industry, as raw materials are more variable than in mining countries, thus having a wider spread of characteristics and because capturing skills might be more advanced.

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